UCRL-CONF-203612

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April 16, 2004

15th Topical Conference on High Temperature Plasma Diagnostics
San Diego, CA, United States
April 19, 2004 through April 22, 2004

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Experimental NIF requirements

Soft x-ray power diagnostics are essential for measuring spectrally resolved the total x-ray flux, radiation temperature, conversion efficiency and albedo that are important quantities for the energetics of indirect drive hohlraums. At the Nova or Omega Laser Facilities, these measurements are performed mainly with Dante [1], but also with DMX [2] and photo-conductive detectors (PCD's) [3]. The Dante broadband spectrometer is a collection of absolute calibrated vacuum x-ray diodes, thin filters and x-ray mirrors used to measure the soft x-ray emission for photon energies above 50 eV.

Compared to NOVA and Omega laser facilities, the National Ignition Facility is designed to achieve indirect drive ignition and to provide a considerably extended range of laser drive flux and thus higher radiation temperatures in the target. Figure 1 shows the range of laser driven soft x-ray flux and the predicted radiation temperatures for different target designs. The flattop hohlraum curves shows the range of soft x-ray flux that can be obtained in hohlraum experiments for full NIF laser power and variable hohlraum size and the NEL (NIF early light) curve shows the similar dependence obtained for full power of the first NIF quad only. The Ignition hohlraum curve gives the range of flux and radiation temperature emitted through the hohlraum laser entrance hole (LEH) during the ICF ignition Haan laser pulse. The NIF and NEL peak power curves are obtained for the peak NIF and NEL laser power considering a variable open source size that is smaller than the Dante field of view for 100% conversion efficiency from laser energy into soft x-rays.

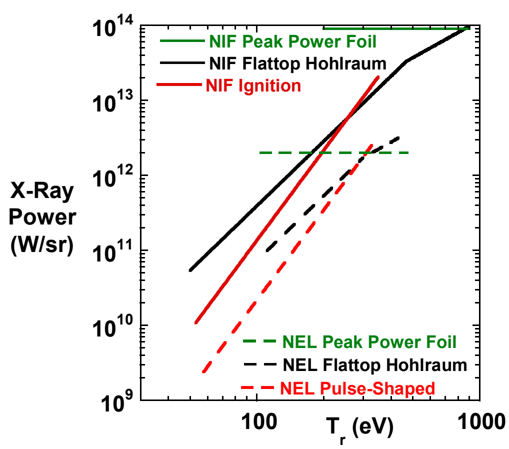
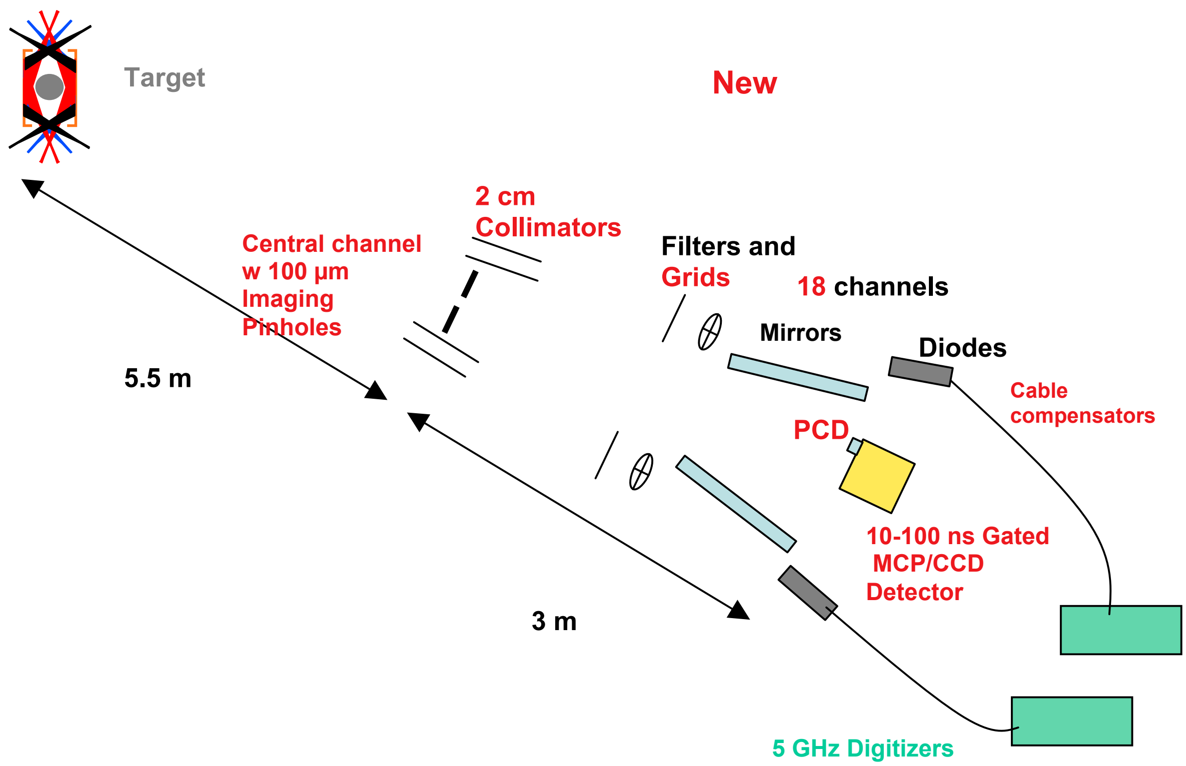


Figure 1

Compared to the Dante spectrometers used at NOVA and Omega laser facilities [1], the Dante developed for NIF will have more broad band channels at > 2keV photon energies due to the higher expected radiation temperatures, as well as a central imaging channel and a photo-conductive detector, as shown in Figure 2. Moreover, NIF Dante will have a considerably increased dynamic range. The imaging channel will measure the radiation source size, position and uniformity, while the PCD will sample the radiation flux emitted by the target in the central part of the source that is not affected by source



boundary non-uniformities. The average detector stand-off distance will be 8.5 m and the field-of-view of the Dante channels, defined by collimators is ±30 mm.

Figure 2 Dante for NIF layout

The broad band energy channels of Dante for NIF

As shown by Figure 1 the new Dante spectrometer will be used to measure radiation temperatures up to 1 keV and fluxes in the 10^{10} to 10^{14} W/cm^2. The high photon energy limit of the Dante channels is given by its requirement to measure 96-99% of the total drive radiation flux. Considering a Planckian black body spectrum, this requirement is met for photon energies of $\leq 10\ kT_r$, where T_r is the radiation temperature. Since for full NIF laser power radiation temperatures approaching 1 keV are predicted analytically, Dante will have 18 broad band channels up to 10 keV photon energies as shown in figure 2. These channels will consist of x-ray diodes, mirrors and filters as given in Table 1, depending on the experiment.

Table 1 Energy channels of Dante for NIF

Low energy resolved channels, similar to Dante working on the Omega laser facility

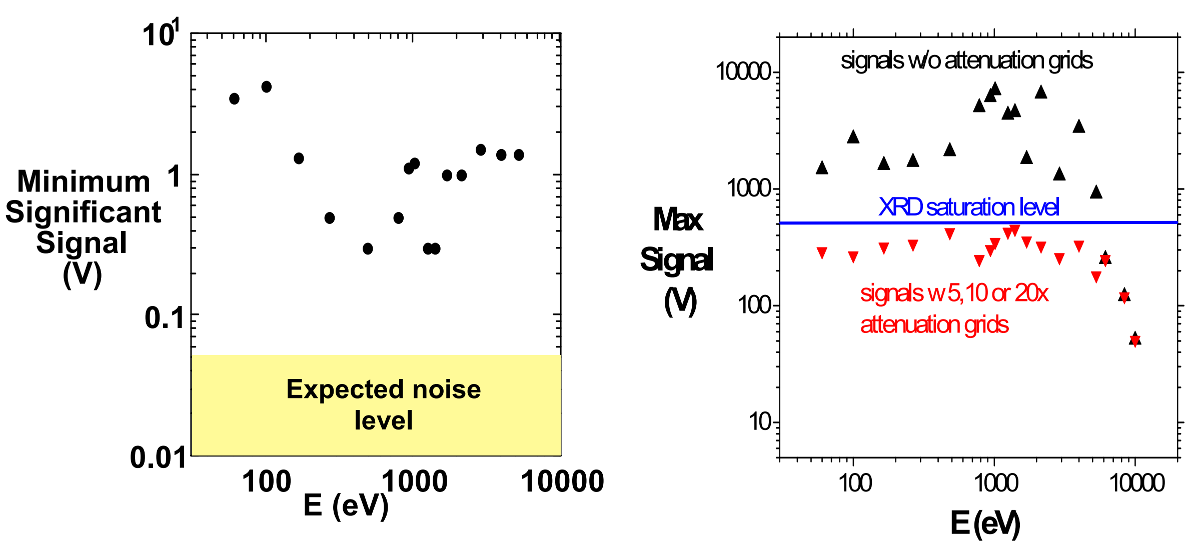
Ch. No	11	12	1	2	3	4	5	6	7	8	9	10
Filter material	Al	Be	B	C	V	Co	Cu	Zn	Mg	Al	Si	Py/Fe/Cr
thickness (µm)	0.76	0.8	0.8	3.6	2	1.6	1.6	1.3	25	15	27	5/1/0.67
x-ray Mirrors	C	C	C	Be	C	-	-	-	-	-	-	-
Phot. Energy (eV)	50-70	90-110	150-180	250-280	450-520	750-820	900-980	980-1050	1200-1300	1300-1500	1600-1800	2000-3000

New high energy channels, similar to DMX

Ch. No	13	14	15	16	17	18	19
Filter material	Mo	Ag	Ti	Mn	Fe	Zn	Al
thickness (µm)	2.5	5.0	20.0	20.0	30	50	500.0
Phot.Energy(keV)	1.8-2.5	2.5-3.3	3.2-4.8	4.3-6.3	5.3-7	7.3-9.5	> 10

The absolute measurement error is given by the calibration procedures used to measure the response functions of the XRD's, x-ray mirrors and filters on the synchrotron at the Brookhaven National Laboratory with a goal of better than 20% in x-ray flux. The first, lower energy 12 channels that cover energies up to 1.8 keV are similar to those of Dante installed at the NOVA and Omega laser facilities, whereas the 7 higher energy channels will be newly added to cover the photon energy range between 1.8 and 10 keV [2]. As shown in Table 1, the channels measuring photon energies below 500 eV have both x-ray edge filters and mirrors to discriminate the filter edge contribution from the high energy contribution that could, in the absence of the mirror generate large errors in the low energy radiation flux measurements. On the other hand, the channels used for photon energies above 500 eV use filters only currently, with the option of adding low angle mirrors in the future for Channels 4 – 6.. The high energy contribution far above the filter edges is then subtracted from each soft individual channel signal using the higher energy channels.

For crosscheck and data continuity purposes, the x-ray diodes that will be used for the new Dante are similar to those installed on the Omega and NOVA laser facilities and have a time response better than 200 ps. The signals expected for each individual channel were calculated considering radiation flux and temperature curves shown in figure 1. For optimal measurements with the XRD's connected to signal cables with 50 Ω impedance, the signal levels should be well above the expected NIF noise level of 50 mV and below the Child-Langmuir limited XRD saturation level of 500 V. Figure 3a shows the signals predicted for the lower limit of the NIF 1st quad curve that will be available soon for experiments.



a ***b***

Figure 3 Predicted signal levels for (a) minimum signal predicted for the first quad and (b) maximum signal of the full NIF curves (Fig. 1) without and with transmission grids

The minimum flux and temperature predicted for NEL yields signal levels considerably higher than the expected noise level. For the upper limit of full NIF power predicted fluxes and temperatures (Fig. 3b), the signals for several channels are 5-20 times higher than the 500 V XRD saturation level. For these high radiation fluxes x-ray attenuation grids will be used to decrease the signal below the saturation point. The transmission grids are the only viable solution since the required increase in filter thickness would result in dominance by high energy components well above edges, causing an unacceptable error increase in determining the filter edge flux component. Such grids or pinhole arrays have been used as achromatic filters for PCDs [4].
High frequency signal attenuators will be used to decrease further the measured signals from the maximum of 500 V XRD saturation level to 10 V which is the upper limit that can be measured with high speed analogue oscilloscopes.
Except for the signal level, the data acquisition system has to satisfy the dynamic range requirements for the planned experiments. Figure 4 shows the required dynamic range shot-to-shot at full NIF encompassing the range of Trs shown in Fig. 1 and for the shaped ICF radiation flux.

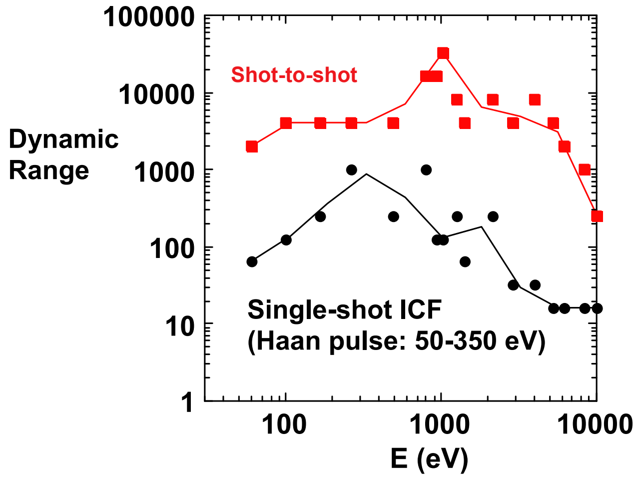
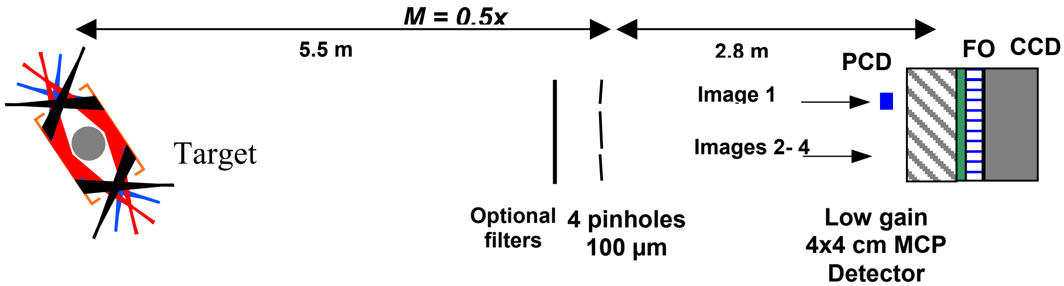


Figure 4 Dynamic range required for the different Dante channels shot-to-shot for full NIF power as well as for the ICF Haan pulse (Fig. 1)

While the shot-to-shot, full NIF and peak power dynamic ranges do not have to be achieved within one shot, the ICF Haan pulse dynamic range of maximum 11 bits has to be covered by the acquisition system in order to measure the x-ray flux and radiation temperature on both foot and peak power laser pulse regions. Since the modern oscilloscopes do not exceed 6 bit at 5 GHz frequency imposed by the required time resolution, signal multiplexing will be used to resolve separately the foot and the peak power fluxes.

Dante PCD and Imaging channel

As mentioned above, the Dante imaging channel will be used to measure the source size and location time integrated over the x-ray pulse in order to ensure XRD alignment to the radiation source. It consists of four 100 μm diameter imaging pinholes with 0.5 magnification and a low gain x-ray microchannel plate (MCP) protected by a thin Be filter and connected to a CCD camera as shown in Figure 5. For measured photon energies higher than 500 eV, the diffraction limited resolution ranges from 400 µm at 300



eV to 150 µm for 3 keV x-rays, with an estimated flux in the 10^4-10^6 photons/µm^2 range.
Figure 5 Layout of the NIF Dante imaging channel

Three of the images formed on the MCP will be used to measure the source size, distribution and location as well as to measure the soft x-ray contribution of the plasma generated by the unconverted IR and green laser light in the Dante FOV. Placed in front of the MCP, a PCD 0.3x0.3x0.3 mm^3 in size will be centered on the fourth image using a high precision motor driven 2-dimensional positioner to sample the x-ray flux in the uniform region of the x-ray radiation source. This will give a time resolved, spectral integrated flux measurement and by comparison with the XRD flux will be used to assess the effects of temporal changes in the radiation source distribution on the measured flux. With the imaging pinholes of 100 um and predicted radiation fluxes (Fig. 1), the expected PCD signal is in a non-saturated regime with an amplitude up to 15 V. The shadow cast by the PCD on the MCP will be used to verify the PCD-source alignment.

Conclusion

The Dante spectrometer for NIF is the core diagnostic for hohlraum performance and for other soft x-ray flux measurements. Through its increased number of XRD channels at photon energies >2 keV and its newly developed imaging channel, it is designed to accommodate various types of experiments and to measure with a precision better than 5% radiation temperatures in the 50 eV to 1 keV range. The higher dynamic range required by ICF and other type of experiments as compared to NOVA and Omega laser facilities will be satisfied by the use of signal multiplexing.

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This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.